Planktonic Larval Duration, Age and Growth of *Ostorhinchus doederleini* (Pisces: Apogonidae) on the Southern Great Barrier Reef, Australia

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Keywords: Apogonidae, otoliths, age, PLD, settlement, growth, mortality.

Abstract

Cardinalfishes (Apogonidae) are abundant on corals reefs, but there are few data on demography to understand trophodynamics and population dynamics. *Ostorhinchus doederleini* is a small and abundant apogonid on the Great Barrier Reef (GBR) and throughout the Western Pacific Ocean. We present key demographic parameters for the entire life history from the southern GBR. Daily deposition of increments in otoliths was validated. Fish had a Planktonic Larval Duration (PLD) of 16 to 26 days. PLD was established from fish collected immediately prior to settlement as no settlement mark was found. Fish grew at about 0.35 mm d^{-1} for the first 20 d after settlement. Fish reached a maximum standard length at about 200 d and no fish lived longer than 368 d at four reefs separated by kilometers to tens of kilometres. There was no evidence for differences in size at age between sexes. Mortality was very high, for fish greater than 60 days old mortality ratesranged from 2.9 to 4.6% per day. Short lives and high mortality rates makes *O. doederleini*, and potentially other apogonids, vulnerable to recruitment failure. Here we review data on the demographic characteristics of other reef fishes. Although some taxa live to over 50 years, the short lives of apogonids are most aligned with the Gobiidae and Blenniidae (i.e. typically < 1.5 years). Descriptions of fish size, age, longevity, growth and mortality; from hatching to age maxima are very rare for most taxa, even at the level of family.

Introduction

Nocturnal fishes are an important trophic group on both coral and temperate reefs (e.g. Marnane and Bellwood 2002; Annesse and Kingsford 2005). Fishes belonging to the Apogonidae, Holocentridae, Nemipteridae and Pempheridae are abundant on reefs and species richness is high (Hobson and Chess 1978; Sale and Douglas 1984; Bellwood 1996; Greenfield 2003; Mabuchi et al. 2006; Thacker and Roje

2009; Gardiner and Jones 2010; Boaden and Kingsford 2012). These taxa feed at night on a range of invertebrates and fishes (Hiatt and Strasberg 1960; Marnane and Bellwood 2002; Annesse and Kingsford 2005; Barnett et al. 2006) and are the prey of many piscivorous taxa (e.g. Kingsford 1992).

Apogonids, and other nocturnal fishes, generally occupy caves and other habitats that provide shelter (e.g. coral Gardiner and Jones 2005) during the day and undergo feeding migrations at night. Movements range from spatial scales of metres to hundreds of metres. In general these fishes feed in habitats that are different from those they occupy during the day (Gladfelter 1979; Marnane 2000; Annesse and Kingsford 2005; Boaden and Kingsford 2012). The trophic importance of these movements to reef ecosystems ~~are~~ is potentially substantial in that their feeding behavior and availability to predators are likely to be significant carbon pathways. Furthermore, feeding behavior often varies with size of fish. Many apogonids and other young nocturnal fishes (Annesse and Kingsford 2005) feed in different habitats than large juveniles and adults (Finn and Kingsford 1996).

Most apogonids have paternal mouth brooding and a larval phase (Brothers et al. 1983). An exception, the apogonid *Pterapogon kauderni* has paternal mouth brooding and direct development of juveniles with no larval phase (Vagelli and Volpedo 2004). Great attention has been given to filial cannibalism of eggs brooded in the buccal cavity of males *O. doederleini* (Okuda and Yanagisawa 1996) and other species (Okuda et al. 1997; 2003; Kume et al. 2000). Despite their novel reproductive biology, trophic importance and the recognition that there is high local population turnover (e.g. on patch reefs Sale and Douglas 1984), there are few data on demography (but see Okuda et al. 1998). An exception is Longenecker and Langston (2006) who found that *Ostorhinchus rubrimacula* (Apogonidae) lived to a maximum of 274 days at a reef in Fiji. There are some estimates of Planktonic Larval Duration (PLD) for 14 species of apogonids in Japan (mean PLDs ranged from 14 to 31 days, Ishihara and Tachihara 2011), but the generality of these values is unknown.

A thorough understanding of population dynamics of any species requires information on growth and mortality at all stages of life history (Hilborn and Walters 1992). The potential for high volatility in population size would be greatest in species that have low age-maxima as there would be little in the way of 'stored' year classes from seasons of high recruitment. Great variation in coral reef fish recruitment among seasons is common (Doherty and Williams 1988), but populations persist, often supported by a small number of large peaks in recruitment (Doherty and Fowler 1994; Kingsford 2009). Apogonids are abundant on tropical reefs, but predation on these fishes is known to be very high (e.g. Sale and Ferrell 1984). We have not found any other studies on the growth of apogonids prior to settlement, immediately after settlement and to their age maxima. We hypothesised that age maxima in *Ostorhinchus doederleini* would be low and this would be consistent among reefs. If this were the case it would greatly influence the outcomes of connectivity among reefs and the persistence of population genotypes. Recent evidence suggests that reef-based local populations of *O. doederleini* can be genetically distinct even when the reefs are only separated by kilometers to tens of kilometers. Is has been proposed that despite the relatively poor swimming abilities of larval apogonids (Stobutzki and Bellwood 1997), they are capable of detecting olfactory cues from their natal reefs and this combined with larval behavior facilitates reduced dispersal that can create genetically distinct populations (Gerlach et al. 2007), but a knowledge of fish demography is essential for a full understanding of connectivity.

The objective of the present study was to describe the growth and mortality of *Ostorhinchus doederleini* (Jordan and Snyder 1901) at four sites within the southern Great Barrier Reef. Wee examined otolith microstructures to (1) validate the aging technique, and (2) determine the Planktonic Larval Duration (PLD), the duration of the presettlement phase. We also, (3) describe the early growth characteristics in presettlement and newly settled fish and (4) potential differences in the growth rates and demographics of fish at multiple reefs. We also provide information on (5) mortality rates based

upon length-at-age estimates of post-settlement fishes. Finally, we (6) review and compare the demographic characteristics of apogonids with other reef fishes.

Materials and methods

Study sites and fish sampling

Ostorhinchus doederleini were sampled at multiple sites on four reefs of the Capricorn Bunker group, southern Great Barrier Reef: Heron Island, One Tree Island, Lamont and Fitzroy reefs (Fig. 1). Presettlement fish were only collected at One Tree Island. Channel nets were set to sample fish on the flood tides only at night in January 1994, February 1995 and February 2009 (Table 1). The net was square mouthed (0.75 x 0.75 m), the mesh was 500 μm, organized as a box/pyramid with an efficiency of 1:12 (mouth area: open sifting surface; full procedures see Kingsford and Finn 1997). To preserve the calcium carbonate of otoliths, subsamples of collections from nets were preserved in ethanol. Samples were then rinsed in alcohol to reduce the seawater content, the final percentage ethanol was 80%. *Ostorhinchus doederleini* entering the lagoon to settle were easily identified by morphology and pigmentation (e.g. a black dot on the caudal peduncle).

Newly settled *O. doederleini* (10 to 18 mm SL) settle on sand and often away from continuous reef (Finn and Kingsford 1996). We constructed six peaked patch reefs on sand (diameter ~ 1.5 m by 0. 5 m maximum height) 20 to 60 m from continuous reef. Patch reefs were monitored on a daily basis and all newly settled fish were collected with fine-meshed hand nets and a wide size range was preserved in 80% ethanol for ageing. Some fish that colonized patch reefs were larger than new settlers (18 to 27 mm SL), but were collected for a description of early post-settlement growth (Table 1).

Juvenile and adult *O. doederleini* were collected at four reefs during January and February of 2009, 2010 and two large individuals in 2013 (Table 1). At each reef we sampled at multiple sites separated by hundreds of metres to tens of kilometers to obtain a representative sample, and fish were pooled for analyses. Juveniles and adults were collected from caves or branching coral, (especially *Porites cylindrica* and branching *Acropora* spp.) and preserved in 80% ethanol. A wide size-range of fish were collected using a mix of 5:1 ethanol: clove oil. At Heron Island and Lamont reef, we sampled all fish from some large patch reefs and this allowed us to estimate mortality rates (see below). Great care was taken to obtain all size classes of fish, especially large individuals that can be missed because they are the most secretive in the backs of caves. Because *O. doederleini* were potentially short-lived (e.g. Longenecker and Langston 2006) we also sampled fish in October 2010 in case the time of sampling altered our estimates of age maxima; these samples did not allow estimates of mortality as only large fish were selected. All fish collected in October 2010 were sexed macroscopically (ie the presence of oocytes in females or fine-grain spermatogenic tissue in males) to determine size and age versus sex relationships.

Otolith preparation

Increments in otoliths were used to obtain estimates of the age and growth of *O. doederleini.* All fish were weighed (± 0.01 g) and then measured (standard length [SL] ± 1 mm). Sagittal otolith pairs were dissected, rinsed in water, and dried overnight. One otolith from each pair was randomly selected, embedded to the edge of a glass microscope slide using Crystal Bond thermoplastic glue. The sulcal groove of the otolith was orientated perpendicular to the surface of the slide and outer edge of the primordium was flush with the inside edge of the slide. Slides were then held vertically and ground to the transverse mid-plane using a Gemmasta GF4 Faceting Machine with a 3000μ diamond encrusted

steel disc. The glue was then reheated and otoliths were remounted with the newly ground surface placed face down in the centre of the glass slide. Otoliths were ground until a thin section (20 µm thick) was obtained which included the primordium.

Analysis of growth increments

The opaque zones visible in the internal structure of the otolith were counted along a radius from the primordium to the outer edge of the otolith from an image taken with a compound microscope (Leica DMLB using a Leica DC300 digital camera); a white incident light source was used. Alternating translucent and opaque increments were interpreted as daily rings; no annuli were observed, even in the largest fish. The counting of increments began from the first clear increment closest to the primordium. Sections were coded and examined in random order and the opaque increments counted on two occasions by the same observer separated by at least seven days. Counts of daily rings were compared between these two occasions in order to assess the confidence that could be placed in the interpretation of otolith structure. If increment counts differed by more than 10% between counting occasions, then the otoliths were re-examined. If, following a third reading, agreement between the third and one of the two other counts was not reached (only closely matching counts were used in analyses), then the otolith was not included in the analysis. To calculate the age, an average of the two closest age estimates was used. Rejection rate over the entire sample was 2.8%, leaving a total sample of n=581 for aging.

Validation of aging technique

To determine the periodicity of increment deposition in *O. doederleini* otoliths, a validation experiment (using tetracycline) was completed at One Tree Island Research Station in January 1994. Fish were treated with tetracycline, it is transported to the endolymph of the inner ear via the blood and deposited

in the otoliths and other bony tissues as a mark (Odense and Logan 1974). The tetracycline mark can be viewed as a fluorescent line under ultraviolet light. The otoliths of 20 untreated fish were examined for autofluorescence.

Newly settled and other juvenile *O. doederleini* between 16.2 and 32.0 mm SL were collected from isolated patch reefs. Fish were collected with a small hand net and transferred to buckets filled with seawater for transport back to the laboratory. They were immersed in tetracycline-treated seawater (0.25 g L^{-1}) for 18 hours in the laboratory in order to mark their otoliths (higher concentrations killed small fish). Fish were transferred to 25 L buckets with one mm mesh windows in the lagoon after removal from the tetracycline solution. Treated fish, therefore, were exposed to the natural cycle of day and night and to normal levels of salinity and water temperature. Fish were fed on wild zooplankton and *Artemia nauplii* that were reared in the laboratory. Fish of a range of sizes were euthanased after five, 10 and 15 d; fish were then preserved in 98% ethanol. Sagittal otoliths were removed, processed and viewed under transmitted and fluorescent light using a compound microscope. Under fluorescent light an ocular marker was aligned with the fluorescent band if present. The otolith was then viewed under natural light and increments counted between the ocular marker and the otolith margin. Processed otoliths from a similar size range of untreated *O. doederleini* were also examined for the presence of auto fluorescence. All otoliths were examined without knowledge of size or treatment.

Spacing of otolith increments

Most reef fish have a mark in otoliths that corresponds with the time of settlement (Brothers et al. 1983). Settlement marks are an abrupt change in increment spacing, usually from wide to narrow (Victor 1986; Kingsford et al. 2011). Our initial observation of otoliths in recently settled fish failed to detect a settlement mark. We tested this more critically by measuring the spacing of increments in eight

randomly selected juvenile *O. doederleini* to determine how the increment pattern changed with distance from the primordium. Transverse sections of the sagittal otolith were prepared. In the first group of fish increment widths were measured from the primordium to the otolith margin (n = 4 fish) and in the second group of fish, from sulcal groove along the longest axis of the otolith to the ventral edge (n = 4 fish) were measured. Increment widths were measured using a calibrated video-analysis system (Leica IM50) linked to a compound microscope (Leica DMLB).

Age and Growth

Growth was described using the von Bertalanffy growth function (VBGF) which provided the best fit to size-at-age data when compared with estimates of the Schnute growth function (Schnute 1981). The von Bertalanffy expression for length at age t (L_t), as a function of time was calculated using equation (1):

$$L_t = L_\infty[1 - e^{-K(t-t_o)}] \qquad (1)$$

where L_t = length at age t *(days)*, L_∞ = the mean asymptotic standard length, K = the rate at which the growth curve approaches L_∞, and t_o = the age at which the fish have a theoretical length of zero. The growth function was run by solver (Microsoft Excel) which minimizes the sum of squares by changing L_∞, K and t_o. Some of our demographic comparisons use 'Age max' = maximum age of an individual within a sample; and adapted from the convention of Choat and Robertson (2002), max 5% refers to the average age of fish from the 95th to 100th percentile, max 10% the average age from the 90th to the 100th percentile of the sample.

205

206 Mortality

207 The instantaneous rate of mortality (*Z*) was calculated using log-linear regression analyses of age-
208 frequency data sets for *O. doederleini* populations from two reefs where all fish from new recruits to
209 large adults were collected. This method assumes that recruitment is consistent over time at each reef
210 (Haddon 2001). Year classes to the left of the age-frequency mode were excluded from the analysis
211 because our sampling technique was biased against small fish. Mortality was only estimated where fish
212 (over 45 mm SL) were collected representatively (i.e. Heron Island and Lamont reef). The slope of the
213 regression line for each reef provided an estimate of daily instantaneous mortality (*Z*); equation (2),
214 when expressed as a percentage = loss of individuals per day.

215 $$Z = F + M \qquad (2)$$

216 where *F* is fishing mortality and *M* is natural mortality (Gust et al. 2002). Since there is not a fishery for
217 *O. doederleini* on the GBR, *F* equals zero and therefore *Z* estimates natural mortality only. Daily
218 survival rate estimates (S) were then calculated (i.e. percentage surviving per day, Ricker 1975)
219 according to the equation (3).

220

221 $$S = e^{-Z} \qquad (3)$$

222

223 Data from each site were pooled for each reef. Similarities in mortality rates among replicate reefs
224 allowed comparisons of mortality between reefs.

Results

Validation of aging

The otoliths of most *Ostorhinchus doederleini* (75%) immersed in tetracycline showed a bright fluorescent band close to the otolith edge (Fig. 2b). Twenty untreated *O. doederleini* otoliths were checked for autofluorescence and showed no fluorescent band (n = 20). There was close agreement between the number of increments laid down from the time of immersion in tetracycline and known number of days since treatment; this was true of fish sampled at 5, 10 and 15 days (Table 2).

Settlement marks were not found in *O. doederleini* regardless of the orientation of counts with respect to the otolith primordium (Fig. 3a & c). There were no rapid changes in increment width that could be attributed to settlement. The approximate age at settlement could be estimated from the average age that potential settlers entered the lagoon to settle (Fig. 3a & b, Table 3). Although increment width varied across the otolith, they did not relate to settlement. Increments close to the primordium ranged from 2 to 4 μm in width and at approximately the 5 to 8 day mark increments rapidly became wider (5 to 7 μm); Fig. 3a. The rapid increase in increment widths at the 5 to 8 day mark was not related to settlement as the mean number of increments in *O. doederleini* caught just prior to settlement was 19.5 (SE = 0.38, n = 34; Table 3). Similar patterns were found in separate profiles, but increments were generally wider (5 to 18 μm) across the profile (Fig.3b).

Age and size of presettlement and recently settled *Ostorhinchus doederleini*

The age of presettlement *O. doederleini* caught in the channel nets ranged from 15.7 to 26.0 days (mean = 19.9; n= 34) and SL ranged from 7.5 to 13.8 mm (mean 10.7; n=34); Table 3. The age of recently settled *O. doederleini* collected from experimental patch reefs ranged from 16 to 42 days (mean= 25.0; n= 232) and SL ranged from 8.6 – 18.0 mm (mean 12.7; n= 677); Table 3.

There was great overlap in the age and size of presettlement fish entering the lagoon and that of recently settled fish. Youngest fish on patch reefs were 16 to 17 days old and were as small as 8.6 mm SL. Older and larger fish were found on patch reefs, but many of them would have been associated with the reef for days as some recently settled fish move between patch reefs (Finn and Kingsford 1996). There was a strong linear relationship between age and standard length in presettlement fish over the first 20 days and recently settled fish and growth was rapid at about 0.~~35~~ 26 mm per day (Fig. 4).

Variation in growth and sizes among reefs

The maximum age of *O. doederleini* among all reefs was 368 days ~~old~~ and at most reefs few fish were older than 200 days old (Fig. 5; Table 4). Time of sampling did not affect estimates of age maxima. The oldest fish caught in Januaryto February at One Tree Island was 284 days and 59 mm long (SL), while in October it was 263 days and 62 mm long (SL). When the average age of the top 5 and 10% of fish was considered at each reef, fish were 150250 days old (Table 4). All von Bertalanffy relationships were well anchored with small fish around 15to 20 mm SL. Best estimates of asymptotic length were obtained from One Tree Island, where fish grew little in length from 150to 200 days old. Although there were no significant differences in the size of fish among reefs in the age range of 90to 110 days (ANOVA, $F_{(3, 60)}$= 0.568, P= 0.63), the maximum size of fish did vary. By reef the average size for the top 5% of fish and the maximum SL was (average, max): One Tree Island (61.0, 66 mm), Heron (57.0, 65 mm); Lamont (62.6, 74 mm) and Fitzroy (65.5, 68 mm). . The largest fish caught at Heron Island, One Tree Island and Fitzroy reef were 65to 70 mm SL (= ~80to 85 Total Length). The two largest and oldest fish ever collected (days/SL, mm: 246/69, 368/74) were from Lamont reef, January 2013. The mean and range of lengths (SL) and ages differed little between males and females (Table 5).

Mortality

Instantanous mortality rates calculated from catch-curves indicated that mortality rates were high for Lamont and Fitzroy reefs(2.9 to4.6 % per day, Fig.6). Further, mortality rates were highest at Lamont where large fish were rare. Survival (S) rates ranged from 0.971 to 0.955 d^{-1}.

Discussion

Ostorhinchus doederleini had a short PLD and once they settled, grew fast and died young. High mortality rates within days of settlement are common for reef fishes (Sale and Ferrell 1988) and low age maxima have been found in other apogonids (Longenecker and Langston 2006). Our study has demonstrated that *O. doederleini* has a high mortality (2.9 to 4.6% per day) and a low age-max. Ages of one year or less clearly put these tropical apogonids at the lower end of the longevity spectrum for tropical fishes along with the Gobiidae and Blenniidae (Table 6). Although some taxa such as gobies may live for less than a year and have high mortality rates (e.g. *Eviota silligata* has an age max of 59 days, mortality rate 7.8% per day; Depczynski and Bellwood 2005), species from families of common reef fishes such as the Pomacentridae (e.g. Doherty and Fowler 1994; Kingsford and Hughes 2005), Labridae (Choat et al. 2006), Scaridae (Choat et al. 1996; Gust et al. 2002), Serranidae, Lutjanidae (Kingsford 2009) and Acanthuridae (Choat and Axe 1996) live for years and sometimes decades (Munday and Jones 1998; Fowler 2009) Table 6. Fishes with the lowest age-max were generally small and represented three different trophic groups: nocturnal planktivores, micro/meso carnivores and herbivores/detrital feeders. Although short-lived reef fish appear to be small, not all small fish are short lived (e.g. *Pomacentrus mollucensis* SL max 90 mm (TL) and age max 18 years; Doherty and Fowler 1994).

To the best of our knowledge, this is the first study to report information on the growth rates of *O. doederleini* prior to settlement and immediately after settlement. Further, it is the first to provide data

294 on longevity (age maxima)of the species in the tropics..Some families had data on multiple stages of life
295 history when multiple species were pooled (e.g. omnivorous/herbivorous damselfishes), but given the
296 differences in demographic characteristics within a family general patterns would be crude or simply
297 inaccurate. There was an abundance of data on age, growth and mortality of representatives of families
298 that are the focus of fisheries, especially macrocarnivores and piscivores such as lutjanids, serranids and
299 carangids. However, data on presettlement growth, PLDs and post-settlement growth was
300 comparatively rare. In other families the focus has only, or primarily, been on early life history stages
301 (e.g. Holocentridae, Pomacentridae). For many important families, we found no data at all on age and
302 growth (e.g. Holocentridae, Pempheridae, Caesionidae and Pomacanthidae). The paucity of data is due
303 in part to a relatively recent understanding that the otoliths of tropical species can provide reliable
304 estimates of age (Meekan et al. 2001). Despite this there is a clear need to increase knowledge in this
305 area for the management reef assemblages and tropical fisheries
306
307 We concluded that accurate estimates of age could be obtained from daily increments. Evidence
308 that counts were accurate included the following: the technique was validated, daily increments were
309 easily observed (Fig. 2), the asymptote for age/length relationship for all reefs was beyond 200 days and,
310 adult fish were collected from a size of 49 mm and 132 days or older (based on brooding fish and
311 macroscopic examination of gonads).
312
313 The oldest fish we found was 368 days (n=581); at 23^{o}35” S) and, unpublished data by Michael
314 Marnane at One Tree Island also indicated that some *O. doederleini* can reach an age of over one year.
315 Similar to our study, Longenecker and Langston (2006) found that *Ostorhinchus rubrimacula*
316 (Apogonidae) lived to a maximum of 280 days in Fiji (17^{o}15” S). However, there are great differences

between our results for *O. doederleini*, and other data from temperate waters in Japan. Okuda et al. (1998) concluded age estimates of up to seven years in at Shikoku Island, Japan (33^{o} 40" N). The fish sampled in Japan grew to a maximum SL of 86 mm SL whereas we only found fish to a size of 74 mm (93 mm TL). The maximum size of *O. doederleini* recorded for the GBR is 90 mm TL ~ 74 mm SL, but no location is given by Randall et al. (1990) for this specimen. Okuda et al. (1998) had few data on fish less than one year for us to make comparisons of age versus a fish of known size. There are three possibilities to explain latitudinal variation in *O. doederleini* age and growth: (1) there are great differences in age over 10 degrees of latitude, which is partly reflected by differences in size max; (2) a methodological issue where the accuracy of aging techniques varies; Okuda et al. (1998) used scales, whereas we used daily increments in otoliths; (3) mortality rates vary greatly between latitudes. With respect to options one and two, we favour option one as latitudinal variation in growth and age maxima are common in fishes (growth, Conover et al. l997; age-max, Boehlert and Kappenman,1980) Furthermore, scales tend to underestimate not overestimate ages. In Japan Okuda et al. (1998) fin clipped some fish that were monitored for up to two years, so they clearly get older than their tropical conspecifics. The apogonid *Apogon ruepillii* found in estuaries near Perth (~ 32^{o}S) were over a year old (Chrystal et al. 1985). All of the evidence from tropical waters indicates that small *O. doederleini* have age maxima of a year or less. Estimates of L_{∞} would be most reliable for all reefs combined (Table 4) as very large fish were rare. Our comparisons of the size/age of fish among reefs in the 80to 90 mm SL range would be robust, but beyond 200 days would be weak. Latitudinal gradients in growth and life span would be interesting to examine. Conover et al. (1997), for example, demonstrated a strong positive correlation between the latitude of origin of *Morone saxatilis* and growth. Further, it is common for there to be positive relationships between life-span and latitude in ectotherms, including fishes (Boehlert and Kappenman,1980; review, Munch and Salinas 2009). At present there are no

340 comparative data on growth by latitude for *O. doederleini*. The presettlement phase of *O. doederleini*
341 was 16 to 26 days and fish settled at 9.5 to 13 mm SL. Settlement marks were not observed and the age
342 of settling fish was determined from potential settlers collected in nets at night and new arrivals to patch
343 reefs. Ishihara and Tachihara (2011) estimated the PLDs of six *O. doederleini* in Japan at ~ 16to 24
344 days and 10to 11.5 mm SL, which fell within the ranges of values we had from the southern GBR; these
345 authors also collected fish in channel nets. The range of ages over which fish settled was 38% of the
346 maximum age at settlement, a little less than that recorded for the damselfish *Pomacentrus coelestis*
347 (45%; Kingsford et al. 2011). Although many damselfishes spend a similar time in the plankton to
348 *O. doederleini*, there are many other taxa that have longer PLDs. For example, scarids have PLDs of 34
349 to 58 days; chaetodonts 25 to 40 and acanthurids 80+ days (Brothers et al. 1983).
350 *Ostorhinchus doederleini* have strong olfactory senses and can respond to the presence of
351 lagoonal waters (Atema et al. 2002). Presettlement fish swim and/or are carried over the reef crest at
352 night (Kingsford 2001) into One Tree lagoon where they find suitable settlement habitat to settle.
353 *Ostorhinchus doederleini* commonly settle away from continuous reef on sections of substratum,
354 potentially to avoid predatory parents (Finn and Kingsford 1996). We demonstrated that during this
355 phase fish had linear growth, this is typical of other fishes during the early juvenile phase (Kingsford &
356 Milicich).
357 Although reef fishes often have a mark in their otoliths related to settlement from pelagic to
358 benthic environments (Brothers et al. 1983; Kingsford et al. 2011), 'settlement marks' were absent in the
359 otoliths of *O. doederleini*. Brothers et al. (1983) also concluded that *O. doederleini* settle at 16to 27
360 days (n=5) and did not mention a settlement mark (='transition'). Settlement marks are not found in all
361 fishes and, it has been speculated that the eco-behavioral transitions are less traumatic in these
362 circumstances (e.g. monacanthids settling from drift algae to algae attached to the substratum, Kingsford

363 and Milicich 1987). *Ostorhinchus doederleini* may experience less post-settlement trauma by not
364 settling on continuous reef, where the risk of predation (and stress) is high. Further, they usually settle
365 with conspecifics (pers. obs.) and they already have an established ability to feed in low light (Job and
366 Bellwood 2000).

367 There is strong evidence that population structure within a metapopulation of *O. doederleini* can
368 be complex at spatial scales of kilometers to tens of kilometers. Despite having a PLD of 16 to 26 days,
369 a combination of favorable oceanography and larval behavior means that a disproportionately high
370 number of fish return to natal reefs and this can result in significant genetic differences among reefs
371 (Gerlach et al. 2007). The robustness of population structures through time is likely to depend on larval
372 survival, physical forcing (Sissenwine 1984), post-settlement processes (Jones 1991; Almany and
373 Webster 2006) and demographic characteristics. It is critical to consider age for numerical modeling of
374 ecological variation in population size and genetic robustness. For short-lived species such as
375 *O. doederleini*, there is a great vulnerability to recruitment failure, especially if they do not have a
376 prolonged spawning season. This in turn could compromise the resistance and resilience of a local
377 genotype to change. Information on the timing and duration of spawning of *O. doederleini* is largely
378 anecdotal, but does suggest a prolonged spawning season. Mouth brooding fish have been observed in
379 October and January-February and peak recruitment is in January to February (i.e. from spawning in
380 December and January), Further, the collection of *O. doederleini* larvae, in June by Kingsford (2001)
381 indicates that at least some spawning occurs in winter and backdating the age of fish collected in
382 January and February puts many birthdates in the Austral winter to spring.

383 In conclusion, *O. doederleini* have a short PLD, they settle onto sand and rubble away from
384 continuous reefs and grow quickly. They reach asymptotic size beyond 200 days, but few fish reach 200
385 days old and the age maximum we found at four reefs was 368 days. These small fish were

386 characterized by high mortality rates and presumably have a high population turn over; this should be
387 considered in models relating to the trophodynamics of reefs and the population biology of
388 *O. doederleini*. A review of the literature indicated that other fishes with similar demographic
389 characteristics are small gobies and blennies.
390

Acknowledgements

We specifically would like to thank One Tree Island Research Station staff and Norm of the *MV Melantra* for our inter reef excursions. This project was funded by ARC Grants to MJK and funding from the ARC Centre of Excellence for Coral Reef Studies. This paper is a contribution from the Reef and Ocean Ecology Laboratory, James Cook University and One Tree Island Field Station.

References

Ahrenholz DW, Morris JA (2010) Larval duration of the lionfish, *Pterois volitans* along the Bahamian Archipelago. Environ Biol Fish 88: 305-309

Almany GR, Webster MS (2006) The predation gauntlet: early post-settlement mortality in reef fishes. Coral Reefs 25: 19-22

Annesse D, Kingsford MJ (2005) Distribution, movements and diet of nocturnal fishes on temperate reefs. Environ Biol Fish 72: 161-174

Atema J, Kingsford MJ, Gerlach G (2002) Larval reef fish could use odour for detection, retention and orientation to reefs. Mar Ecol Prog Ser 241: 151-160

Barnett A, Bellwood DR, Hoey AS (2006) Trophic ecomorphology of cardinalfish. Mar Ecol Prog Ser 322: 249-257

Bay LK, Beuchler K, Gagliano M, Caley MJ (2006) Intraspecific vairiation in the pelagic larval duration of tropical reef fishes. J Fish Biol 68: 1206-1214

Beldade R, Pedro T, Goncalves EJ (2007) Pelagic larval duration of 10 temperate cryptobenthic fishes. J Fish Biol 71: 376-382

Bellwood DR (1996) The Eocene fishes of Monte Bolca: The earliest coral reef fish assemblage. Coral Reefs 15: 11-19

Bernardes RA (2002) Age, growth and longevity of the grey triggerfish, *Balistes capriscus* (Tetraodontiformes: Balistidae), from the Southeastern Brazilian Coast. Scientia Marina 66: 167-173

417 Berumen ML (2005) The importance of juveniles in modelling growth: Butterflyfish at Lizard Island.
418 Environ Biol Fish 72: 409-413
419 Berumen ML, Trip EDL, Pratchett MS, Choat JH (2012) Differences in demographic traits of four
420 butterflyfish species between two reefs of the Great Barrier Reef separated by 1,200 km. Coral
421 Reefs 31: 169-177
422 Boaden AE, Kingsford MJ (2012) Diel behaviour and trophic ecology of *Scolopsis bilineatus*
423 (Nemipteridae). Coral Reefs 31: 871-883
424 Boehlert GW, Kappenman RF (1980) Variation of growth with latitude of two species of rock fishes
425 (*Sebastes pinniger* and *S. diploproa*) from the North Eastern Pacific Ocean Mar Ecol Prog Ser 3:
426 1-10
427 Brewer DT, Blaber SJM, Milton DA, Salini JP (1994) Aspects of the biology of *Caranx bucculentus*
428 (Teleostei, Carangidae) from the Gulf of Carpentaria, Australia. Aust J Mar Freshw Res 45: 413-
429 427
430 Brothers EB, Williams DM, Sale PF (1983) Length of larval life in twelve families of fishes at One Tree
431 Lagoon, Great Barrier Reef, Australia. Mar Biol 76: 319-324
432 Brown IW, Sumpton WD (1998) Age, growth and mortality of redthroat emperor *Lethrinus miniatus*
433 (Pisces: Lethrinidae) from the southern Great Barrier Reef, Queensland, Australia. Bull Mar Sci
434 62: 905-917
435 Choat JH, Axe LM (1996) Growth and longevity in acanthurid fishes: an analysis of otolith increments.
436 Mar Ecol Prog Ser 134: 15-26
437 Choat JH, Axe LM, Lou DC (1996) Growth and longevity in fishes of the family Scaridae. Mar Ecol
438 Prog Ser 145: 33-41
439 Choat JH, Davies CR, Ackerman JL, Mapstone BD (2006) Age structure and growth in a large teleost,
440 *Cheilinus undulatus*, with a review of size distribution in labrid fishes. Mar Ecol Prog Ser 318:
441 237-246

442 Choat, J.H. and Robertson, D.R. (2002) Age-based studies. In Sale PF (2002) Coral Reef Fishes:
443 Dynamics and diversity in a complex ecosystem. p57-80. Academic Press, San Diego California
444 Choat JH, Robertson DR, Ackerman JL, Posada JM (2003) An age-based demographic analysis of the
445 Caribbean stoplight parrotfish *Sparisoma viride*. Mar Ecol Prog Ser 246: 265-277
446 Chrystal PJ, Potter IC, Loneragan NR, Holt C P (1985). Age structure, growth rates, movement patterns
447 and feeding in an estuarine population of the cardinalfish *Apogon ruepelli*. Mar Biol 85: 185-197
448 Chung KC, Woo NYS (1999) Age and growth by scale analysis of *Pomacanthus imperator* (Teleostei:
449 Pomacanthidae) from Dongsha Islands, southern China. Environ Biol Fish 55: 399-412 Conover
450 DO, Brown JJ, Ehtisham A (1997) Countergradient variation in growth of young striped bass
451 (*Morone saxatilis*) from different latitudes. Can J Fish Aquat Sci 54: 2401-2409
452 Conover DO, Brown JJ, Ehtisham A (1997) Countergradient variation in growth of young striped bass
453 (*Morone saxatilis*) from different latitudes. Can J Fish Aquat Sci 54: 2401-2409
454 Currey LM, Williams AJ, Mapstone BD, Davies CR, Carlos G, Welch DJ, Simpfendorfer CA, Ballagh
455 AC, Penny A, Grandcourt EM, Mapleston A, Wiebkin AS, Bean K (2013) Comparative biology
456 of tropical Lethrinus species (Lethrinidae): challenges for multi-species management. J Fish Biol
457 82: 764-788
458 de Albuquerque CQ, Martins AS, Leite ND, de Araujo JN, Ribeiro AM (2011) Age and growth of the
459 queen triggerfish *Balistes vetula* (Tetraodontiformes, Balistidae) of the central coast of Brazil.
460 Braz J Oceanogr 59: 231-239
461 Depczynski M, Bellwood DR (2005) Shortest recorded vertebrate lifespan found in a coral reef fish.
462 Current Biol 15: R288-R289
463 Depczynski M, Bellwood DR (2006) Extremes, plasticity, and invariance in vertebrate life history traits:
464 Insights from coral reef fishes. Ecology 87: 3119-3127
465 Doherty P, Fowler T (1994) An empirical test of recruitment limitation in a coral reef fish. Science 263:
466 935-939
467 Doherty PJ, Williams DM (1988) The replenishment of coral reef fish populations. Oceanography and
468 Marine Biology an Annual Review 26: 487-551

469 Finn MD, Kingsford MJ (1996) Two-phase recruitment of a coral reef fish (Pisces: Apogonidae) on the
470 Great Barrier Reef. Mar Freshw Res 47: 423-432
471 Fowler AJ (1989) Description, interpretation and use of the microstructure of otoliths from juvenile
472 butterflyfishes (Family Chaetodontidae). Mar Biol 102: 167-181
473 Fowler AJ (2009) Age in years from otoliths of adult tropical fish. In: Green BS, Mapstone BD, Carlos
474 G Begg GA (ed) Tropical fish otoliths: Information for assessment, management and ecology.
475 Springer 11: 55-92
476 Gardiner NM, Jones GP (2005) Habitat specialisation and overlap in a guild of coral reef cardinalfishes
477 (Apogonidae). Mar Ecol Prog Ser 305: 163-175
478 Gardiner NM, Jones GP (2010) Synergistic effects of habitat preference and gregarious behaviour on
479 habitat use in coral reef cardinal fish. Coral Reefs 29: 845-856
480 Gerlach G, Atema J, Kingsford MJ, Black KP, Miller-Sims V (2007) Smelling home can prevent
481 dispersal of reef fish larvae. PNAS 104: 858-863
482 Gladfelter WB (1979) Twilight migrations and foraging activities of the copper sweeper *Pempheris*
483 *schombirgki* (Teleostei: Pempheridae). Mar Biol 50: 109-119
484 Green BS, McCormick MI (2005) Maternal and paternal effects determine size, growth and performance
485 in larvae of a tropical reef fish. Mar Ecol Prog Ser 289: 263-272
486 Greenfield DW (2003) Coral Reef Fishes: Dynamics and diversity in a complex ecosystem. Copeia
487 2003: 214-216
488 Gust N, Choat JH, Ackerman JL (2002) Demographic plasticity in tropical reef fishes. Mar Biol 140:
489 1039-1051
490 Haddon M (2001) Modelling and Quantitiative Methods in Fisheries. Boca Raton, Chapman and
491 Hall/CRC. 406 p.

492 Heupel MR, Williams AJ, Welch DJ, Davies CR, Adams S, Carlos G, Mapstone BD (2010)
493 Demography of a large exploited grouper, *Plectropomus laevis*: Implications for fisheries
494 management. Mar Freshw Res 61: 184-195
495 Heupel MR, Williams AJ, Welch DJ, Davies CR, Penny A, Kritzer JP, Marriott RJ, Mapstone BD
496 (2010) Demographic characteristics of exploited tropical lutjanids: a comparative analysis. Fish
497 Bull 108: 420-432
498 Hiatt RW, Strasburg DW (1960) Ecological relationships of the fish fauna on coral reefs of the Marshall
499 Islands. Ecol Monogr 30: 65-127
500 Hilborn R, Walters CJ (1992) Quantitative fisheries stock assessment. Chapman & Hall, London
501 Hobson ES, Chess JR (1978) Trophic relationships among fishes and plankton in the lagoon at
502 Enewetak atoll, Marshall Islands. Fish Bull US 76: 133-153
503 Ishihara T, Tachihara K (2011) Pelagic Larval Duration and Settlement Size of Apogonidae, Labridae,
504 Scaridae, and Tripterygiidae Species in a Coral Lagoon of Okinawa Island, Southern Japan. Pac
505 Sci 65: 87-93
506 Job S, Bellwood DR (2000) Light sensitivity in larval fishes: implications for vertical zonation in the
507 pelagic zone. Limnol Oceanog 45: 362-371
508 Jones GP (1991) Postrecruitment processes in the ecology of coral reef fish populations: a multifactorial
509 perspective. In: Sale PF (ed) The Ecology of fishes on coral reefs. Academic Press, New York,
510 pp 294-328
511 Kerrigan BA (1996) Temporal patterns in size and condition at settlement in two tropical reef fishes
512 (Pomacentridae: *Pomacentrus amboinensis* and *P. nagasakiensis*). Mar Ecol Prog Ser 135: 27-41
513 Kingsford M J, Hughes J M (2005) Patterns of growth, mortality and size of a tropical damselfish
514 *Acanthochromis polyacanthus* across the continental shelf of the Great Barrier Reef. Fish Bull
515 103: 561-573

516 Kingsford MJ (1992) Spatial and temporal variation in predation on reef-fishes by coral trout
517 (*Plectropomus leopardus*), Serranidae. Coral Reefs 11: 193-198
518 Kingsford MJ (2001) Diel patterns of arrival of reef fish to a coral reef: One Tree Island, Great Barrier
519 Reef. Mar Biol 138: 853-868
520 Kingsford MJ (2009) Contrasting patterns of reef utilization and recruitment of coral trout
521 (*Plectropomus leopardus*) and snapper (*Lutjanus carponotatus*) at One Tree Island, southern
522 Great Barrier Reef. Coral Reefs 28: 251-264
523 Kingsford MJ, Finn M (1997) The influence of phase of the moon and physical processes on the input of
524 presettlement fishes to coral reefs. J Fish Biol 51 (Supplement A): 176-205
525 Kingsford MJ, Milicich MJ (1987). Presettlement phase of *Parika scaber* (Pisces: Monacanthidae): a
526 temperate reef fish. Mar Ecol Prog Ser 36: 65-79
527 Kingsford MJ, Smith FJA, Flood MJ (2011) Growth and pelagic larval duration of presettlement and
528 newly settled neon damselfish, *Pomacentrus coelestis*, at multiple spatial scales. Coral Reefs 30:
529 203-214
530 Kume GA, Yamaguchi GA, Taniuchi T (2000). Filial cannibalism in the paternal mouthbrooding
531 cardinalfish *Apogon lineatus*: Egg production by the female as the nutrition source for the
532 mouthbrooding male. Environ Biol Fish 58: 233-236
533 Longenecker K, Langston R (2006) Life history characteristics of a small cardinalfish, *Ostorhinchus*
534 *rubrimacula* (Percoidei: Apogonidae), from Koro, Fiji. Pac Sci 60: 225-233
535 Mabuchi K, Okuda N, Nishida M (2006). Molecular phylogeny and stripe pattern evolution in the
536 cardinalfish genus *Apogon*. Mol Phylo Evol 38: 90-99
537 Marnane MJ (2000) Site fidelity and homing behaviour in coral reef cardinalfishes. J Fish Biol 57:
538 1590-1600

539 Marnane MJ, Bellwood DR (2002) Diet and nocturnal foraging in cardinalfishes, (Apogonidae) at One
540 Tree Reef, Great Barrier Reef, Australia. Mar Ecol Prog Ser 231: 261-268
541 Marriott RJ, Mapstone BD, Begg GA (2007) Age-specific demographic parameters, and their
542 implications for management of the red bass, *Lutjanus bohar* (Forsskal 1775): A large, long-
543 lived reef fish. Fish Res 83: 204-215
544 Meekan MG, Ackerman JL, Wellington GM (2001) Demography and age structures of coral reef
545 damselfishes in the tropical eastern Pacific Ocean. Mar Ecol Prog Ser 212: 223-232
546 Mosse JA, Adams S, and Welch DJ (2002) Bommie cod (*Cephalopholis cyanostigma*): A big surprise
547 from a little fish. In Williams AJ, Welch DJ, Muldoon G, Marriott R, Kritzer JP, and Adams S.
548 (eds) (2002) Bridging the gap: A workshop linking student research with fisheries stakeholders.
549 p90-101, CRC Reef Research Centre Technical Report No. 48, CRC Reef Research Centre,
550 Townsville.
551 Munch SB, Salinas S (2009) Latitudinal variation in lifespan is explained by the metabolic theory of
552 biology. Proceedings of the National Academy of Sciences of the United States of America 106:
553 13860-13864
554
555 Munday PL, Jones GP (1998) The ecological implications of small body size among coral-reef fishes.
556 Oceanogr Mar Biol Ann Rev 36: 373-412
557 Newman SJ, Cappo M, Williams DM (2000) Age, growth, mortality rates and corresponding yield
558 estimates using otoliths of the tropical red snappers, *Lutjanus erythropterus*, *L. malabaricus* and
559 *L. sebae*, from the central Great Barrier Reef. Fish Res 48: 1-14
560 Newman SJ, Williams DM, Russ GR (1996) Variability in the population structure of *Lutjanus adetii*
561 (Castelnau, 1873) and *L. quinquelineatus* (Bloch, 1790) among reefs in the central Great Barrier
562 Reef, Australia. Fish Bull 94: 313-329
563 Odense P H, and Logan V H (1974) Marking atlantic salmon (*Salmo salar*) with oxytetracycline. J Fish
564 Res Brd Can 31: 348-350
565 Okuda N, Fukumori K, Yanagisawa Y (2003) Male ornamentation and its condition-dependence in a
566 paternal mouthbrooding cardinalfish with extraordinary sex roles. J Ethol 21: 153-159

567 Okuda N, Takeyama T, Tanagisawa Y (1997) Age-specific filial cannibalism in a paternal
568 mouthbrooding fish. Behav Ecol Sociobiol 41: 363-369
569 Okuda N, Tayasu I, Yanagisawa Y (1998) Determinate growth in a paternal mouth brooding fish whose
570 reproductive success is limited by buccal capacity. Evol Ecol 12: 681-699
571 Okuda N, Yanagisawa Y (1996) Filial cannibalism by mouthbrooding males of the cardinal fish, *Apogon*
572 *doederleini*, in relation to their physical condition. Environ Biol Fish 45: 397-404
573 Pears RJ, Choat JH, Mapstone BD, Begg GA (2006) Demography of a large grouper, *Epinephelus*
574 *fuscoguttatus*, from Australia's Great Barrier Reef: implications for fishery management. Mar
575 Ecol Prog Ser 307: 259-272
576 Randall JE, Allen GR, Steene RC (1990) Fishes of the Great Barrier Reef and Coral Sea. Crawford
577 House Press, Bathhurst
578 Ricker WE (1975) Computation and interpretation of biological statistics of fish populations, Bull 191.
579 Fish Res Brd Can, Ottawa, Canada
580 Sale PF, Douglas WA (1984) Temporal variability in the community structure of fish on coral patch
581 reefs and the relation of community structure to reef structure. Ecology 65: 409-422
582 Sale PF, Ferrell D (1988) Early life survivorship of coral reef fishes. Coral Reefs 7: 117-124
583 Schnute J (1981) A versatile growth model with statistically stable parameters. Can J Fish Aquat Sci 38:
584 1128-1140
585 Sissenwine MP (1984) Why do fish communities vary? In: May RM (ed) Exploitation of Marine
586 Communites. Springer-Verlag, Berlin, pp 50-94
587 Stobutzki I, Bellwood DR (1997) Sustained swimming abilities of the late pelagic stages of coral reef
588 fishes. Mar Ecol Prog Ser 149: 35-41
589 Sudekum AE, Parrish JD, Radtke RL, Ralston S (1991) Life history and ecology of large jacks in
590 undisturbed, shallow, oceanic communities. Fish Bull 89: 493-513

591 Thacker CE and Roje DM (2009) Phylogeny of cardinalfishes (Teleostei: Gobiiformes: Apogonidae)
592 and the evolution of visceral bioluminescence. Mol Phylo Evol 52: 735-745
593 Tyler JC, Johnson GD, Brothers EB, Tyler DM, Smith CL (1993). Comparative early-life histories of
594 western Atlantic squirrelfishes (Holocentridae) - age and settlement of rhynchichthys, meeki, and
595 juvenile stages. Bull Mar Sci 53: 1126-1150
596 Vagelli AA, Volpedo AV (2004) Reproductive ecology of *Pterapogon kauderni*, an endemic apogonid
597 from Indonesia with direct development. Environ Biol Fish 70: 235-245
598 Victor BC (1982) Daily otolith increments and recruitment in two coral-reef wrasses, *Thalassoma*
599 *bifasciatum* and *Halichoeres bivittatus*. Mar Biol 71: 203-208
600 Victor BC (1986) Duration of the planktonic larval stage of 100 species of Pacific and Atlantic wrasses
601 (Family Labridae). Mar Biol 90: 317-326
602 Victor BC, Vasquez-Yeomans L, Valdez-Moreno M, Wilk L, Jones DL, Lara MR, Caldow C, Shivji M
603 (2010) The larval, juvenile, and adult stages of the Caribbean goby, *Coryphopterus kuna*
604 (Teleostei: Gobiidae): a reef fish with a pelagic larval duration longer than the post-settlement
605 lifespan. Zootaxa 2346: 53-61
606 Wellington GM, Victor BC (1989) Planktonic larval duration of 100 species of Pacific and Atlantic
607 damselfishes (Pomacentridae). Mar Biol 101: 557-567
608 Williams AJ, Davies RD, Mapstone BD, Currey LM, Welch DJ, Begg GA, Ballagh AC, Choat JH,
609 Murchie CD, Simpfendorfer CA (2009) Age-based demography of humpback grouper
610 *Cromileptes altivelis*: implications for fisheries management and conservation. Endangered
611 Species Research 9: 67-79
612 Wilson SK (2004) Growth, mortality and turnover rates of a small detritivorous fish. Mar Ecol Prog Ser
613 284: 253-259
614

615 **Table 1** Collection details for *Ostorhinchus doederleini* specimens, 1994 to 2013. OTI- One Tree Island;

616 H- Heron Reef; F- Fitzroy Reef; and L= Lamont.

617

Dates Sampled	Methods used	Reefs	Life stage
Jan 1994	Channel nets; Patch Reefs	OTI	Presettlement and early post-settlement
Feb 1995	Channel nets; Patch Reefs	OTI	Presettlement and early post-settlement
Feb 2009	Channel nets, Hand nets; clove oil	OTI, H, F, L	Juveniles and adults
Jan-Feb. 2010	Hand nets; clove oil	OTI, H, F, L	Juveniles and adults
Oct 2010	Hand nets; clove oil	OTI	Juveniles and adults
Jan 2013	Hand nets; clove oil	L	Adults

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621 **Table 2** Results of validation marking experiments for *Ostorhinchus doederleini*. No. of days = number

622 of days since fish were immersed in tetracycline.

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No. of days	*n*	SL range (mm)	Mean of counts (SE)
5	42	17.0 - 25.2	4.95 (0.07)
10	16	17.4 - 34.0	10.06 (0.11)
15	11	16.2 - 25.0	14.82 (0.23)

624

Table 3 Age (days) and size (mm; SL) of presettlement and recently settled *Ostorhinchus doederleini* in two recruitment seasons. Data shown are the mean (range) and total n is given by row. For recently settled fish n varied for size and age, more fish were collected for measurements of size and were not preserved in ethanol (Kingsford and Finn 1997).

	1994	1995	*n*
Presettlement fish			
SL	10.7 (7.5 - 13.0) 4	10.6 (9.0 - 13.8) 30	34
Age	18 (15.7 - 19.7) 4	19.7 (16.0 - 26.0) 30	34
Recently settled fish			
SL	14.1 (9.8 - 18.0) 299	11.23 (8.6 - 18.0) 378	677
Age	28.2 (17.0 - 41.5) 113	22.5 (16.0 - 40.0) 119	232

631

632 **Table 4** von Bertalanffy growth parameters for four reefs and estimates of age maxima for individual
633 fish from samples at each location and average age of the oldest five and 10 percent of fish (i.e. Max %).
634

Reef	n	L∞	K	r^2	Age Max	Max 5% (n) SE	Max10% (n) SE
Heron	122	76.24	0.008	0.86	215	173 (6) 13	144 (12) 11
One Tree Island	257	60.76	0.012	0.88	284	255 (13) 4	240 (26) 4
Lamont	91	83.84	0.006	0.82	368	213 (5) 6	176 (9) 27
Fitzroy	123	70.48	0.009	0.77	282	224 (6) 12	207 (12) 8
All reefs	593	65.04	0.010	0.89	368	249 (30) 5	226 (59) 4

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640 **Table 5** Size, age and sex differences for *Ostorhinus doederleini* collected at One Tree Island, October
641 2010.

	Female	Male
n	55	70
Mean (SL)	53.27 mm	52.09 mm
SE	0.535	0.596
Min (SL)	43 mm	41 mm
Max (SL)	60 mm	66 mm
Mean (Age)	191 days	190 days
Min (Age)	139 days	132 days
Max (Age)	258 days	263 days

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Table 6 A comparison of with examples of demographic characteristics among multiple families of tropical reef fishes, by trophic groups (adapted from Randall et al. 1990); in some cases we found more references than listed, but the age range was within the other publication listed. A Yes (Y) indicates that some information is available; ND- no data, y- years, d- days. Brothers et al. (1983) provided estimates of PLD for many of the groups listed, but they relied on the presence of settlement marks which are not found in some families such as apogonids. Some families appear in more than one trophic group (e.g. Pomacentridae). Data from temperate regions are not included.

Family	Species	Presettlement growth	PLD (range)	Settlement mark	Early Post-settlement growth	Life time growth	Age maxima	Estimates of mortality	Country	Source
Nocturnal planktivores/piscivores										
Apogonidae	*Apogon cyanosoma*	N	18-19d	ND	ND	ND	ND	ND	GBR, Australia	Brothers et al. 1983
	Cheilodipterus quinquelineatus	N	17-29d	ND	ND	ND	ND	ND	GBR, Australia	Brothers et al. 1983
	Ostorhinchus doederleini	Y	16-26d	ND	Y	Y	< 1 year	Y	GBR, Australia	This study
	Ostorhinchus rubrimacula	N	N	ND	Y	Y	< 1 year	ND	Fiji	Longenecker and Langston 2006
Holocentridae	Multiple (7)	Y	32-56d	ND	ND	ND	ND	ND	Western Atlantic	Tyler et al. 1993
Pempheridae		ND	ND	ND	ND	ND	ND	ND		
Diurnal planktivores										
Caesionidae		ND	ND	ND	ND	ND	ND	ND		
Pomacentridae	Multiple (8)	ND	8-32d	Y	Y	ND	ND	ND	GBR, Australia	Bay et al. 2006; Green and McCormick 2005
Acanthuridae	*Naso sp* (6)	ND	ND	ND	ND	Y	9-30y	ND	GBR, Australia	Choat and Robertson 2002

Serranidae	e.g. *Anthias* spp. and *Pseudoanthias* spp	ND	ND	ND	ND	ND	ND	ND		
Micro-Meso carnivores										
Balistidae	Multiple (2)	ND	ND	ND	ND	Y	11-14y	Y	Brazil	de Albuquerque et al. 2011; Bernardes 2002
Chaetodontidae	Multiple (8)	Y	23-45d	Y	Y	Y	6-20y	Y	GBR, Australia	Fowler 1989; Berumen 2005; Berumen et al. 2012
Gobiidae	Multiple (3)	ND	24-26d	Y	Y	Y	59-100d	Y	GBR, Australia	Depczynski and Bellwood 2006
	Coryphopterus kuna	ND	45-74d	Y	Y	Y	120d	Y	Caribbean	Victor et al. 2010
	Eviota sigillata	ND	23-27d	Y	Y	Y	59d	Y	GBR, Australia	Depczynski and Bellwood 2005
Labridae	Multiple (9)	ND	21-50d	Y	ND	Y	15-36y	Y	GBR, Australia	Brothers et al. 1983; Choat et al. 2006
	Thalassoma bifasciatum	Y	40-72d	Y	Y	ND	ND	ND	Caribbean	Victor 1982
Nemipteridae	*Scolopsis bilineatus*	ND	ND	ND	ND	Y	16	Y	GBR, Australia	Boaden and Kingsford 2012
Pomacanthidae	*Pomacanthus imperator*	ND	ND	ND	ND	Y	16	ND	China	Chung and Woo 1999
Macrocarnivore/ piscivore										
Carangidae	Multiple (2)	ND	ND	ND	ND	Y	6-10y	ND	Hawaii	Sudekum et al. 1991
	Caranx bucculentus	ND	ND	ND	ND	Y	ND	Y	Northern Australia	Brewer et al. 1994
Lethrinidae	Multiple (7)	ND	ND	ND	ND	Y	15-36y	Y	GBR, Australia	Currey et al. 2013; Brown and Sumpton 1998
Lutjanidae	Multiple (11)	ND	ND	ND	ND	Y	12-55y	Y	Northern Australia, Indonesia	Marriott et al. 2007; Newman et al. 1996; Newman et al. 2000; Heupel et al. 2010
	Lutjanus carponotatus	ND	ND	ND	ND	Y	18y	Y	GBR, Australia	Kingsford 2009
Scorpaenidae	*Pterois volitans*	ND	20-35d	ND	ND	ND	ND	ND	Bahamas	Ahrenholz and Morris 2010
Serranidae	*Cephalopholis cyanostigma*	ND	ND	ND	ND	Y	45y	Y	GBR, Australia	Mosse et al. 2002
	Cromileptes altivelis	ND	ND	ND	ND	Y	19y	Y	GBR, Australia	Williams et al. 2009

	Epinephelus fuscoguttatus	ND	ND	ND	ND	Y	42y	Y	GBR, Australia	Pears et al. 2006
	Plectropomus laevis	ND	ND	ND	ND	Y	16y	Y	GBR, Australia	Heupel et al. 2010
	Plectropomus leopardus	ND	ND	ND	ND	Y	15y	Y	GBR, Australia	Kingsford 2009
Omnivores/herbivores/ scrapers and detrital feeder										
Acanthuridae	Multiple (5)	ND	84d	Y	ND	Y	21-70y	ND	GBR, Australia	Choat and Axe 1996
Blenniidae	Multiple (3)	ND	12-33d	Y	ND	ND	ND	ND	GBR, Australia	Beldade et al. 2007; Brothers et al. 1983
	Salarias patzneri	ND	ND	Y	Y	ND	350d	ND	GBR, Australia	Wilson 2004
Pomacentridae	Multiple (100)	Y	12-39d	Y	ND	ND	ND	ND	GBR, Australia; 'acific, Atlantic	Bay et al. 2006; Wellington and Victor 1989
	Acanthochromis polyacanthus	ND	ND	Y	Y	N	9-11y	Y	GBR, Australia	Kingsford and Hughes 2005
	Pomacentrus amboinensis	Y	15-23d	ND	ND	ND	ND	ND	GBR, Australia	Kerrigan 1996
	Pomacentrus coelestis	Y	15-27d	Y	Y	ND	ND	ND	GBR, Australia	Kingsford et al. 2011
	Pomacentrus moluccensis	ND	ND	ND	Y	Y	18y	Y	GBR, Australia	Doherty and Fowler 1994
	Stegastes acapulcoensis	ND	ND	ND	ND	Y	12-32y	Y	Panama, Galapagos	Meekan et al. 2001
Scaridae	Multiple (7)	Y	30-50d	Y	ND	Y	5-20y	Y	GBR, Australia	Brothers et al. 1983; Gust et al. 2002; Choat et al. 1996
	Sparisoma viride	ND	ND	ND	ND	Y	7-9y	Y	Caribbean	Choat et al. 2003

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646 **Figure Captions**

647

648 **Fig. 1** Map showing the location of the four reefs in the Capricorn-Bunker Group, southern Great
649 Barrier Reef, Australia where *Ostorhinchus doederleini* was collected.
650
651 **Fig. 2** (a) Sagittal otolith section of a 21 day old *Ostorhinchus doederleini.* Width of otolith section is
652 1500 µm. Initial measurement made at first visible increment (Insert showing enlargement of
653 300 µm long)*;* (b) Otolith of a fish euthanised 10 days after immersion in tetracycline viewed under UV
654 light, scale bar = 100 µm; (c) A section of an 90 day old fish (from OTI; 34 mm SL) showing track used
655 for aging, which extended from the primordium to the outer edge of the otolith along the longest axis
656 (Section is 2100 µm long).
657
658 **Fig. 3** Otolith increment widths plotted as a function of increment number for a subset of four post-
659 settlement *Ostorhinchus doederleini*, (a) 1994 and 1995; (b) 2010 from One Tree Island, Great Barrier
660 Reef, Australia. The dotted vertical line indicates the mean no. of increments deposited by presettlement
661 apogonids caught just prior to settlement measured from the primordium to along the sulcal groove;
662 from the primordium to the ventral edge of the otolith. Initial measurement made at first visible
663 increment.
664
665 **Fig. 4** Relationship between standard length and age (days) of presettlement versus newly settled
666 recruits *Ostorhinchus doederleini* in 1994 and 1995 together with fitted regression lines and summary
667 statistics.
668
669 **Fig. 5** von Bertalanffy growth curves for *Ostorhinchus doederleini* for the four reefs in the Capricorn
670 Bunker group, Great Barrier Reef, Australia.
671
672 **Fig 6** Age-based 'catch-curves' that provide estimates of mortality for *Ostorhinchus doederleini* for
673 Heron and Lamont reefs in the Capricorn Bunker group, Great Barrier Reef, Australia; each data point
674 indicates Log_e frequency of each age class.
675

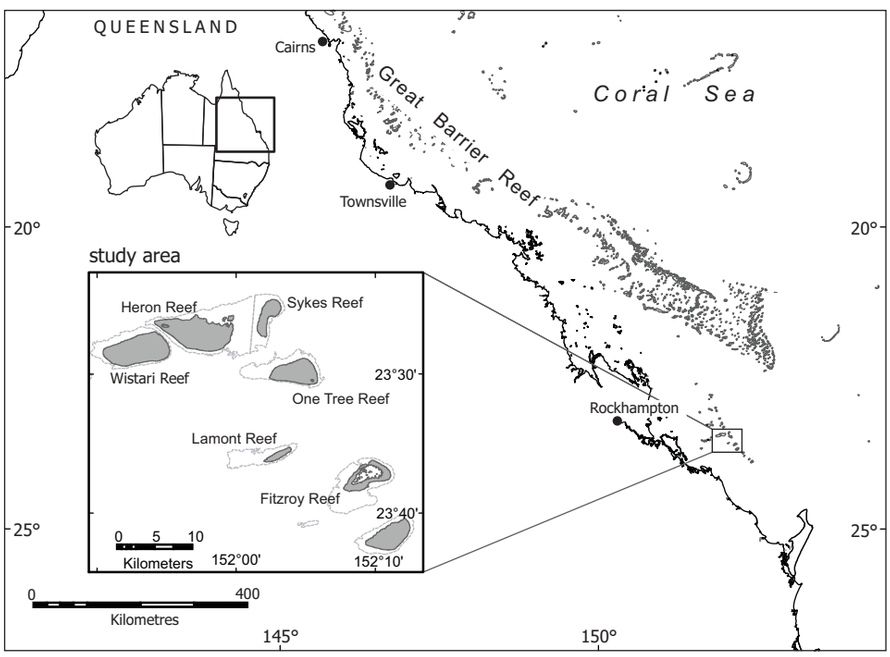
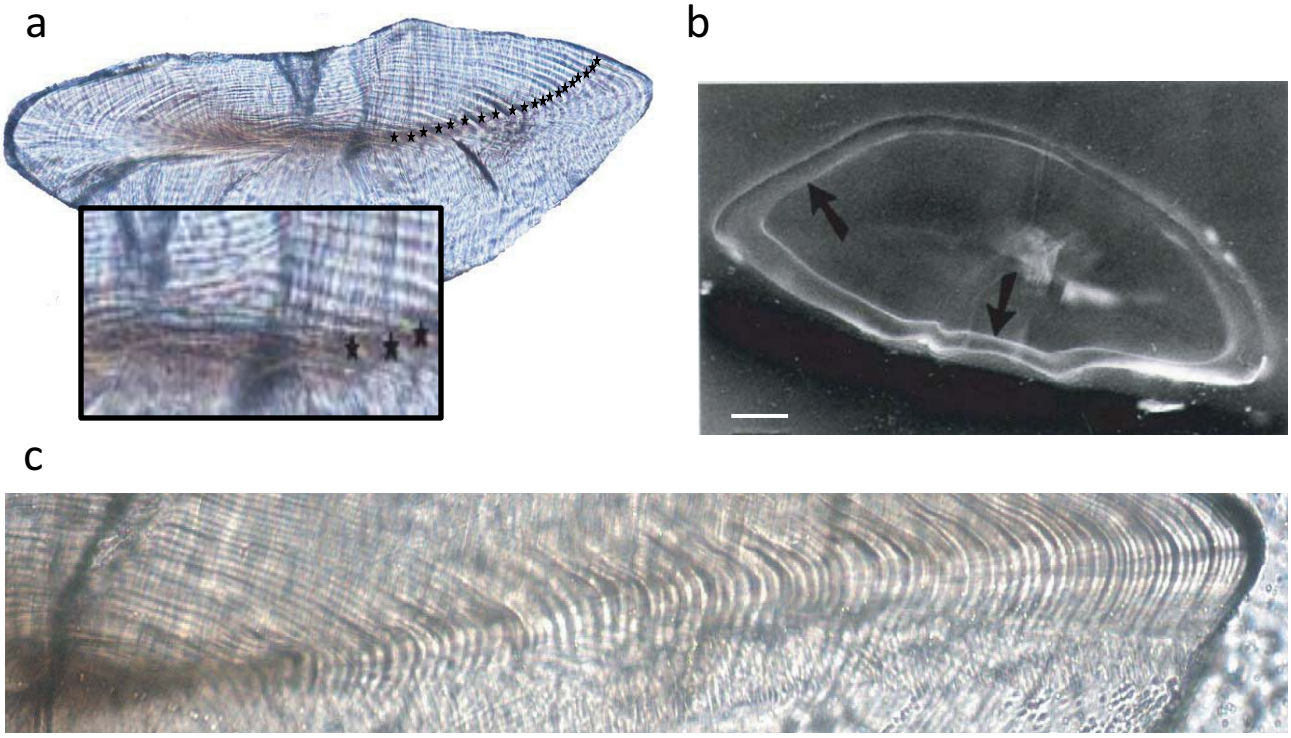
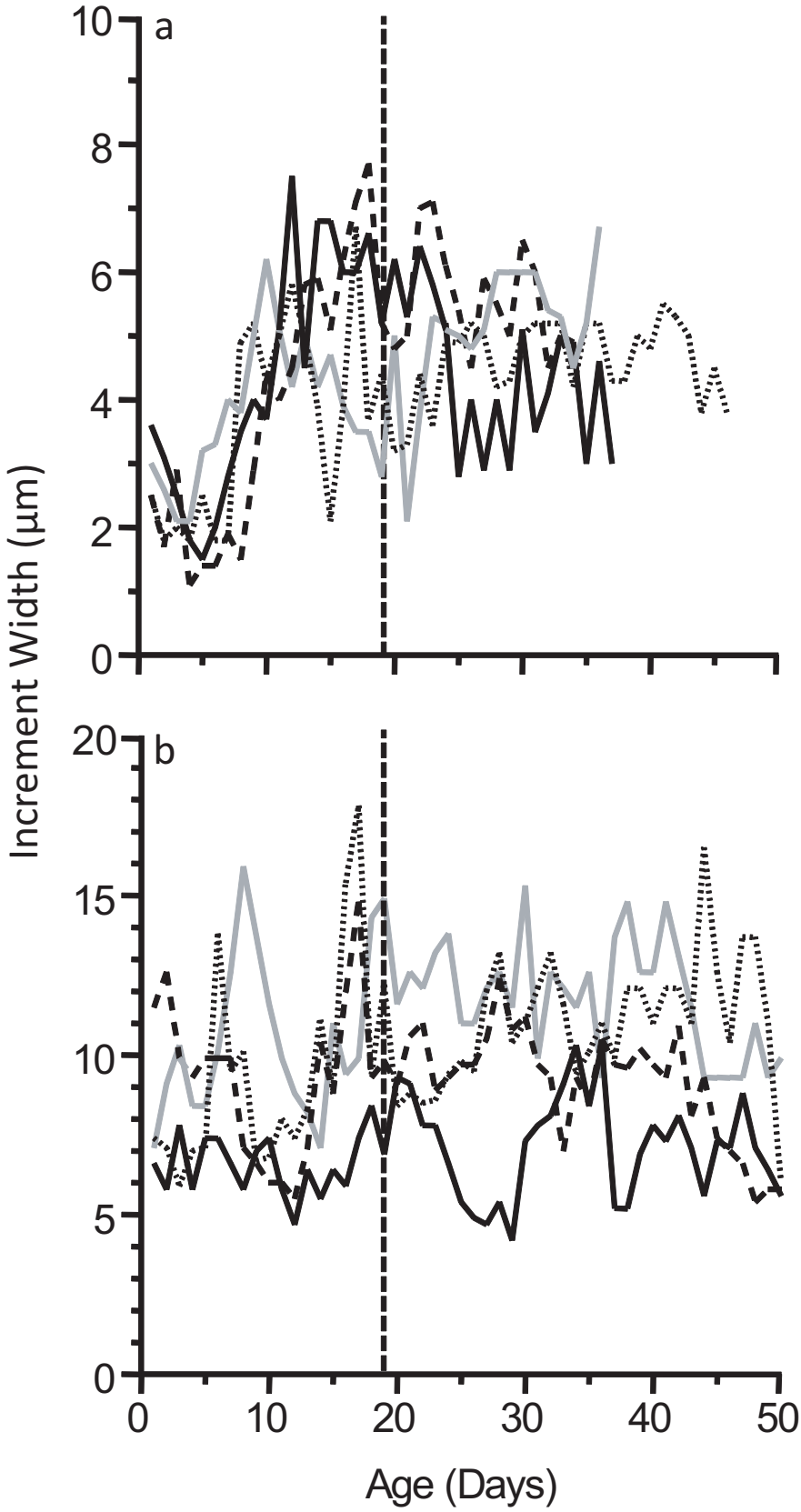
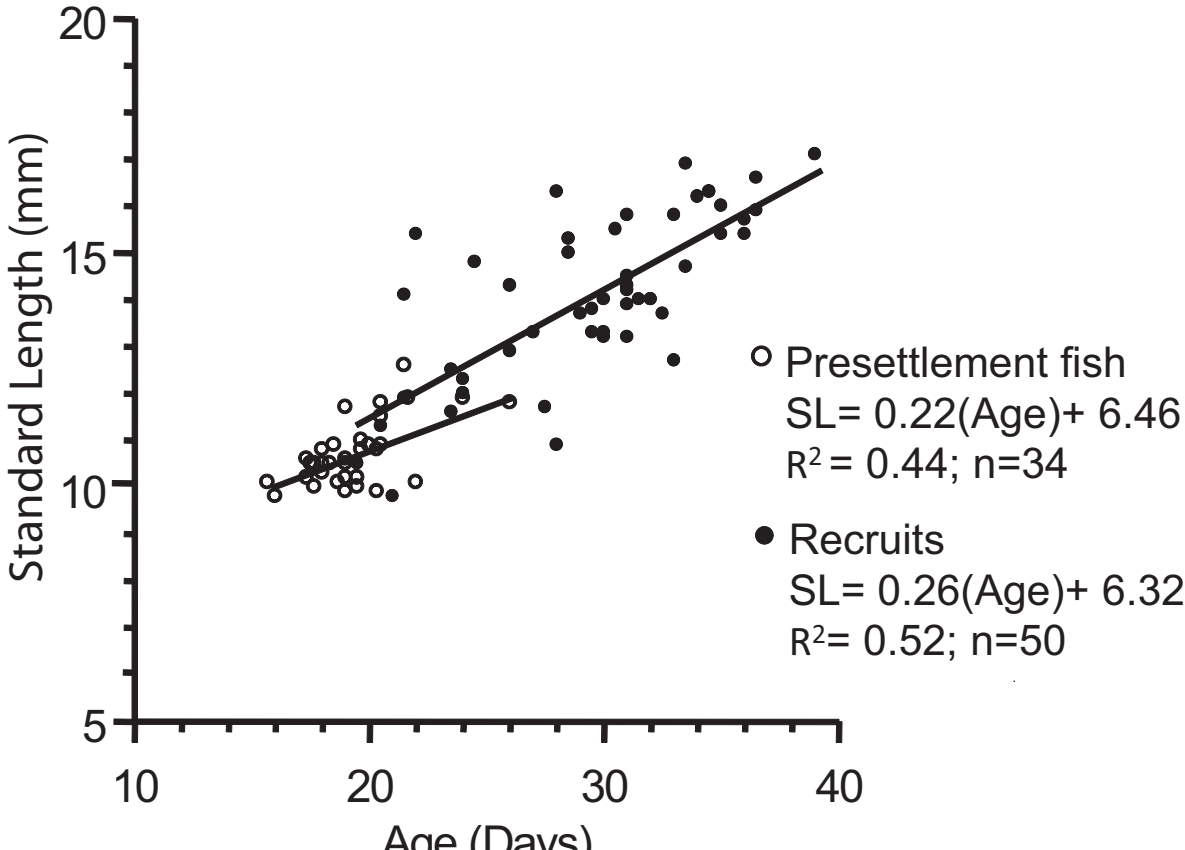
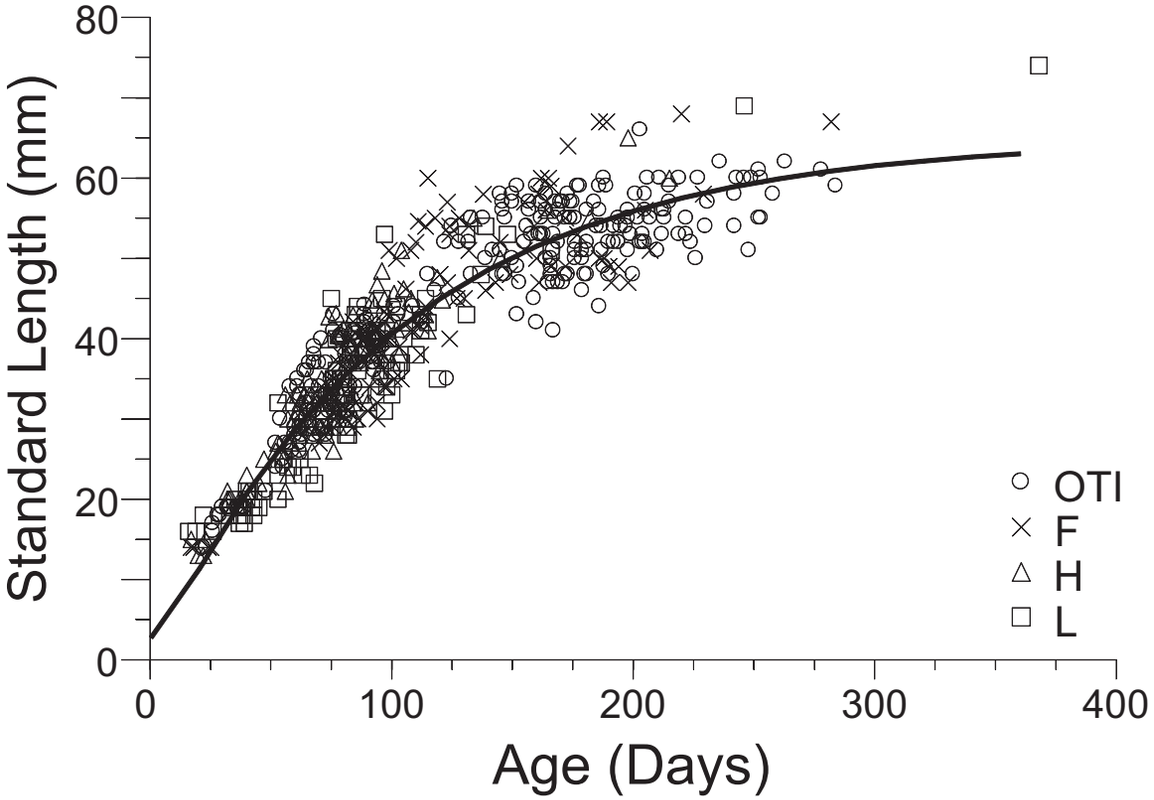

QUEENSLAND
Cairns
Townsville
Great Barrier Reef
Coral Sea
Rockhampton
20°
25°
145°
150°
study area
Heron Reef
Sykes Reef
Wistari Reef
One Tree Reef
Lamont Reef
Fitzroy Reef
23°30'
23°40'
152°00'
152°10'
0 5 10
Kilometers
0 400
Kilometres

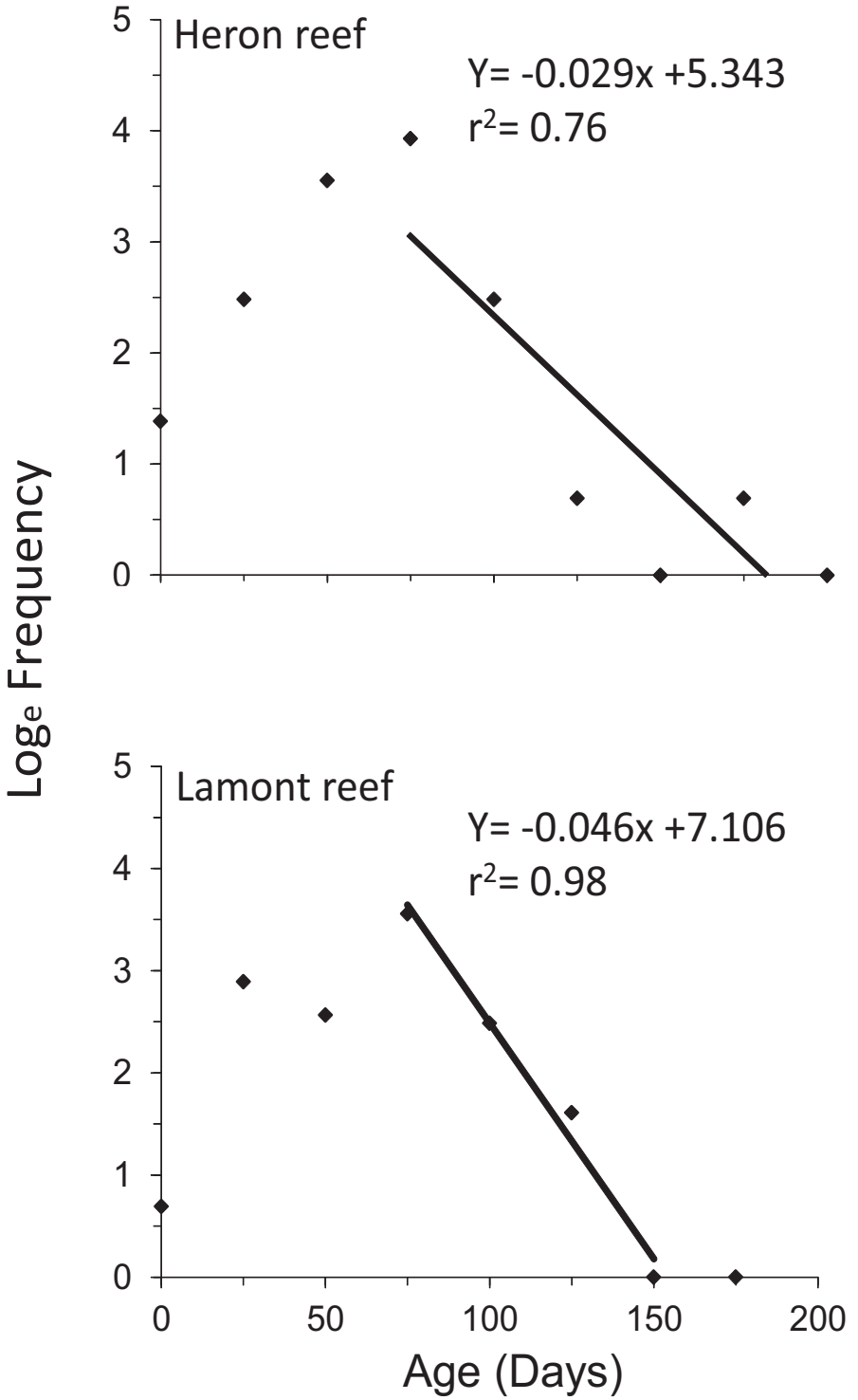
Figure 2




a
b
Increment Width (µm)
Age (Days)
0
2
4
6
8
10
0
5
10
15
20
0
10
20
30
40
50


20
15
10
5
Standard Length (mm)
10
20
30
40
Age (Days)
Presettlement fish
SL= 0.22(Age)+ 6.46
R2 = 0.44; n=34
Recruits
SL= 0.26(Age)+ 6.32
R2= 0.52; n=50


Standard Length (mm)
0
20
40
60
80
0
100
200
300
400
Age (Days)
OTI
F
H
L


Heron reef
Y= -0.029x +5.343
r2= 0.76
Lamont reef
Y= -0.046x +7.106
r2= 0.98
Loge Frequency
Age (Days)
0
1
2
3
4
5
0
50
100
150
200